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# PRELIMINARY REPORT ON THE PRESENT STATE OF KNOWLEDGE CONCERNING IMPACT TESTS.

Presented at the second Annual Meeting of the American Section, August 15 and 16, 1899, by Professors W. Kendrick Hatt and Edgar Marburg.

## Prefatory Statement.

The members of this Committee regret that they have found themselves unable to complete, in time for this meeting, the program upon which they had agreed. Thus the proposed compilation of a descriptive bibliography relating to impact tests and impact machines, though fairly well advanced, is not sufficiently near completion, especially with respect to foreign publications, to warrant presentation at this time. Again, the account of impact machines constructed for purposes of scientific research is decidedly fragmentary. Concerning some of the later machines little or nothing has, in fact, been published. The current methods of what may be called commercial impact testing also deserve more extended and detailed notice than they have here received.

What follows is offered, therefore, merely as a preliminary report without pretensions to completeness. Besides some general matters relating to impact tests, the report contains a partial review of the more recent experimental researches on the mechanical properties of metals as revealed by impact, of the characteristic features of various machines, and a brief summary of opinions as to the value of impact tests in practice and the methods used

or recommended. The latter information was elicited through inquiries addressed to various engineers, railroad officials, testing laboratories and manufacturing concerns.

It is to be stated also, that tests of a character approaching that of true impact tests, such as vibration tests (for stay bolts), rattler tests (for brick), and tests for hardness under falling weights were not considered as coming within the scope of the present inquiry. Cold bending and drifting tests, though somewhat of the nature of impact tests, were excluded for like reasons.

## General Considerations.

The use of impact tests in a crude form has been resorted to from early times as a ready means of forming some judgment of the quality of material. This early use may be attributed to the following advantages: (1) The possibility of making such tests on larger manufactured pieces by means of simple, inexpensive appliances; (2) the ease and quickness with which results may be obtained; and (3) the apparently intimate relation between the action of the test and many of the common conditions of service.

The development of slow-testing machines, the operation of which was not only more easily controlled, but yielded far more definite results, led to a concentration of interest upon slow-testing methods and the innumerable problems connected therewith to the comparative neglect of impact testing. During that period which has witnessed the evolution of machinery for static tests to its present high state of perfection, investigations upon impact action have been relatively few, and, as a rule, inadequately planned. Nor has the subject engaged the long-continued attention of any single investigator. Moreover, the treatment of problems relating to resilience has been inadequately set forth in the text-books of mechanics, although this defect is now gradually disappearing.

A revival of interest is becoming apparent also in the experimental side of the subject, in its practical as well as in its scientific bearing. Thus, the action of the Pennsylvania Railroad and the Master Car Builders' Association in standardizing machines with spring foundation for the anvil for impact tests of axles and rails, may be instanced as a decided step towards the elimination of some of the chief sources of that irregularity in the results which has been the basis of much of the opposition to impact tests. The standard specifications for car-coupler tests, recently issued by the Master Car Builders' Association, also deserve notice in this connection.

In this country the use of impact tests is restricted mainly to rails, couplers, axles, and car-wheels, although small cast-iron

bars are not infrequently subjected to such tests. In Germany and in France the impact test has found a wider range of application.

Thus, according to Professor Martens, shock tests for practical purposes have been made at the Charlottenburg Station upon gun-shot, stone, roof-covering materials, wire cables, cast-iron plates, in addition to the more strictly scientific investigations. These tests were made in compression, tension, bending, shearing and punching. In a review of the work of the Station for the year, 1897–98, appearing in the current volume of Baumaterialienkunde, it is stated that 43 shock tests were made out of a total of 2315 of all kinds. These included 25 on cast iron, 10 on caulks for horseshoes, 6 on rivet iron, and 2 on axles.

Impact tests for axles, wheels, rails and tires are also common in Germany.

In France shock tests in tension as well as bending are applied to materials for guns, to forged steel, rails, rail-chairs, tires, and steel shells.

Apart from such commercial tests, an increasing activity in the scientific study of the mechanical properties of materials under impact action is quite noticeable. Professor Martens has given particular attention to compression under shock to which further reference will be made hereafter. The behavior of the metal in tension and in bending under impact has also received some study.

It is particularly gratifying to note that in America impact machines have been constructed, or are in process of construction, at the laboratories of the U. S. Arsenal at Watertown, Mass., Lehigh University, Purdue University, the Virginia Polytechnic Institute, and McGill University. These machines are intended for scientific research which will have to be devoted primarily to obtaining the requisite fundamental data for placing impact testing on a more definite basis. Studies in tension and bending, and compression tests on steel, iron, cement, and stone are contemplated. Results derived from the pendulum machines of W. J. Keep and W. Bent Russell have already been published. The former has recently constructed a larger and improved form of his machine and is now engaged upon tests, the results of which are promised for early publication.

One of the most important questions connected with impact testing is: To what extent is the resilience under slow tension a measure of the resilience under shock? To answer this question, comparative tests under many varying conditions, as to material, dimensions and form of specimen, temperature, etc., will have to be made under such conditions that the work performed in deforming the specimen can be measured within reasonable limits of accuracy. Since this work is the product of force by deformation, any incidental deformation of the apparatus will be at the ex-

pense of the energy of the blow. The work of deforming the specimen is necessarily less, in all cases, than the total energy expended by the hammer. There is no great difficulty, however, in getting a closely approximate measure of the work performed upon the apparatus. The necessity of rigidity in the apparatus has been insisted upon in recent discussions, and this matter has doubtless received due consideration in the later machines.

The practical difficulties of impact tests in tension are sufficiently evident. In compression there is the advantage, that the entire volume of the metal is more uniformly deformed, whereas in tension the specimen does not deform uniformly as a whole, but has a partly elastic and partly plastic deformation irregularly distributed.

The influence of temperature on the results of rail, axle, and coupler tests demands more attention than it has yet received. As a rule these tests are made in the open air; so that, apart from the varying rigidity of the soil, largely compensated for by the insertion of springs under the anvil, there yet remains the increased brittleness of the material at low temperatures under shock as a disturbing element of a quite serious nature. Since such tests aim chiefly at comparative results, it is essential that they should be predicated upon conditions as nearly fixed as can be obtained by ordinary means.

When one pauses to consider the time and labor that have been expended in placing the methods of slow testing on a correct basis, one can better realize the magnitude of the task in prospect with regard to the much more complicated shock test. The principles and laws are not only more obscure, but the problems in machine design involved are far more difficult.

## Impact Machines.

For flexure tests the ordinary commercial machine consists of a hammer falling, between rail guides, on the center of the rail or axle, which is supported on rounded cast-iron or steel abutments, the latter forming part of the anvil. In the most approved practice the anvil rests on a nest of calibrated springs of specified quality and size.

For tension tests several types of machines have been used. At the Charlottenburg Station the specimen is hung to an iron trestle (the anvil) and to the lower end of the specimen (held in wedges) is attached a frame, movable between vertical guides. The hammer strikes this frame, and the shock is communicated to the specimen. Evidently only comparative results under fixed conditions can be obtained. Another machine of the same type is used in this laboratory for testing wire cables. The hammer, guided by a gas pipe surrounding the cable, and falling on a

weight at the lower end of the specimen is, by proper machinery, allowed to deform the cable 13 times per minute.

In another type of machine for longitudinal shock in tension, used in France, the specimen is arranged with an upper head, while the hammer, properly guided is hung to a head or bushing on the lower end of the specimen. The specimen and hammer are lifted together by an attachment to the upper head, and then released. In the descent the upper head catches on a bridge between the uprights of the machine and impact results. This type of machine was used by Colonel Maitland in 1887, and by Mr. Comstock in testing wire cables at Cornell University in 1895. If a pencil be attached to the hammer and allowed to write a velocity-elongation curve on a revolving drum, this type of machine is susceptible of scientific use. In this form it has been used for the past two years at Purdue University in tests of steel and iron wire.

Modern machines of the pendulum type, for impact tests in bending, are represented by the well-known apparatus of W. S. Keep; and that of W. Bent Russell. In the machine designed by the latter great rigidity of foundation for the anvil was provided. The pendulum consists of a steel plate, so hung that the blow is delivered at the center of percussion of the plate, and provision is made for ascertaining the velocity of the pendulum before and after impact.

Professor Martens refers to a machine of the ballistic pendulum type designed by Professor Kick for scientific purposes. Both hammer and anvil are suspended by wires with adjusting screws so as to bring the center lines of the cylindrical hammer and anvil to coincidence. The specimen (for compression) is fixed to the anvil. The hammer is raised by a string to the desired height along the vertical arc of its movement. For release, the string is burnt. That part of the energy of the blow expended on the anvil is measured by the rise of the latter along the vertical arc of its motion.

A machine of this type has lately been completed at Lehigh University for testing cement briquettes under impact in flexure.

"The machine at the United States Arsenal, at Watertown, is of the vertical type. It has an anvil block, to which the anvil is secured, weighing 30,000 pounds; and this is supported upon a base also weighing about 30,000 pounds. Side rods carry a cross head and hydraulic cylinder, by means of which the hammer is raised. A hydraulic grip on the end of the piston rod of the cylinder directly engages a stem on the hammer, raising and releasing the latter at the desired height of fall. Hammers of different weights will be used up to 1 ton; and heights of fall giving striking velocities up to 20 feet per second.

"In general, it is intended to investigate the effect of rapidly applied stresses on different metals, observing phenomena within the elastic limit of the material in one class of tests and the phenomena which accompany stresses which cause permanent deformations in another class. Attention will center on the actual resistance encountered in both elastic and permanent deformations, comparing in this respect the results under slowly applied loads with those obtained at different rates of speed. This involves a determination of the resistance of the metal at each instant throughout the deformation, which it is intended to accomplish."[1]

The results developed will appear in the Annual Report of Tests of Metals and Other Materials.

Dr. R. Moldenke proposes, as a useful type of machine for cast iron, a pendulum machine in which the pendulum is to strike transversely the free end of a test-bar, which is clamped firmly at one end.

William Kent has designed a machine for longitudinal shock in which a number of specimens may be tested at the same time. A weight raised by a cam falls on a head attached to the lower end of each specimen.

In all impact machines, matters which should receive particular attention are: Friction, which should not be greater than 2 per-cent; coincidence of center lines of hammer and anvil; parallelism of faces of hammer and anvil; inertia of anvil; shape and material of striking edge of hammer when the latter is curved; guided length of hammer; and method of release. The suggestion has been made that some form of electro-magnet would be the best solution of the problem of release.

German specifications provide that machines shall be officially tested.

At the conference held in Vienna in 1893 for the unification of methods of testing, W. Schmitz presented a detailed and illustrated description of two impact machines, then in course of construction, which he had designed in conformity with the requirements prescribed in 1888 by the *Verein deutscher Eisenbahn-Verwaltungen*, for the testing of car-axles and wheels.

## Review of Experimental Data.

The state of knowledge up to 1894 has been so well reviewed by Professor Merriman in an address before the Section of Mechanical Science and Engineering of the American Association for the Advancement of Science, delivered in August, 1894, that it seems necessary only to consider in some detail experiments undertaken since that time.

[1] Extract from letter written to the Committee by Col. J. W. Reilly, Commanding Officer, Watertown Arsenal.

It may be said in general that the main problems for experiment are those in which the deformation exceeds that at the elastic limit. The conclusions from a purely mathematical treatment, usually confined to elastic deformation, are amply confirmed by tests made within the elastic limit; and confirmed also by tests up to rupture on materials whose elastic limit approaches the breaking strength. While it is highly important that theoretical considerations should be kept in mind in arranging and interpreting experiments, yet the solution of the main problems relating to impact must depend chiefly upon experiment, concerned as they are with total resilience. There is, for example, strong evidence pointing to the fact that certain materials, and other materials under certain conditions, vary greatly in their resilience according to the rapidity of application of the energy to the specimen. In the investigation of the influence of this and numerous other elements lies the work of experimentation, the end of which should be the framing of adequate specifications for tests.

The early experiments of Tredgold, Hodgkinson, Willis and Galton are well known. The laws of impact for cast-iron beams were determined, and the proportionality of resilience to volume and the effect of the inertia of the beams noted. The later experiments of Kirkaldy, Uchatius, Maitland and Estrada, on ductile materials have resulted in increased knowledge, although the data are too meagre for formulation; or even for the reconciliation of apparent contradictions.

As the speed at which the ordinary testing machine is run is increased, the ultimate strength and elastic limit seem slightly to increase, and the elongation to decrease; although, for tests of from about one to six minutes' duration no differences can be measured which are greater than the ordinary differences in quality of bars cut from the same plate. However, no extension of the facts gained from observations upon the effects of differences of speed of the ordinary testing machines can be applied to cases of impact.

The following is a brief and incomplete review of the more recent experiments:

### *Tension Tests.*

Kirkaldy, 1862, found that wrought iron specimens broke under loads suddenly applied without impact with 82 per-cent of the load under slow tests. Uchatius, 1874, noted the increased total energy required to break a bar under a number of light blows compared with that required when broken with a single blow. Maitland, 1887, showed that in the case of unhardened gun steel the ultimate elongation was increased by impact. The specimens were 2 inches between shoulders; and broke in slow

testing at 58,000 pounds per square inch with 27 per-cent elongation. The elongation under shock was 47 per-cent, when shock was produced by a falling weight. Specimens were also screwed into plugs fitting in a strong tube and broken by exploding gunpowder and guncotton between the plugs. The ultimate elongation was then 47 to 62 per-cent. The increased elongation is probably explained by the more uniform distribution of the elongation over the entire length of the specimen instead of its localization at a single neck. Estrada, 1893, made tests in longitudinal impact on nickel steel, armor plate, bridge steel and iron merchant bar, in test pieces of the same size as in slow tension tests. Tests were made at varying temperatures under the blow of a 100 pound hammer falling through heights varying from 1/2 to 25 feet. Accompanying tests were made in slow tension. A large amount of the energy of the hammer was absorbed in the apparatus. Rupture was brought about by a number of blows. The ultimate elongation under shock with a number of blows was about two-thirds greater than in the case of slow tension. The contraction of area remained about the same.

Recently, experiments in longitudinal impact were made in Austria by Captains Kuczera and Reinisch, on metals for gun carriages. The rods were of a 3/16 inch diameter and were subjected to light blows at temperatures of 68° and -4° F. Contrary to other experiences, these rods withstood a greater number of blows and developed greater extension at the lower temperature. Rupture of transverse nicked bars on the contrary was produced with fewer blows at the lower temperature.

In the *Report of the French Commission*, Le Chatelier has two reports which furnish data upon impact. The first, on the influence of duration of test ; and the second on the effects of temperature. The main part of the first report deals with tests too slow for impact action. He notes the property which certain materials possess of adjusting themselves to a load, so that the elongation increases to a limiting value at the end of long periods ; and the further property whereby the load at rupture increases with tests of shorter time. The latter is especially marked in the case of zinc which ruptured for a 60-minute test under less than 1/2 the load producing rupture in one minute. Steel, iron, copper and aluminum did not exhibit this characteristic in any marked degree. In the case of copper, the effect of high temperatures, (200°, 350° and 440° C. were used) is to augment the influence of high speed in producing higher values of both ultimate load and ultimate elongation. The effect of the rate of application of the load upon the elongation is variable. Opposite results were found for materials of different degrees of hardness and for stresses of different degrees of intensity. Tests by Barba, Privat,

and Le Chatelier, on wires broken with speeds varying between 11 minutes and 4 seconds, showed that for metals of small contraction of area, both the per cent of elongation, and ultimate load increases with increase of speed; and that for metals of large contraction of area like soft steel, the elongation decreases as the speed increases, down to a duration of one minute, but that for tests quicker than one minute the elongation increases again.

Referring to impact proper, it was noted that, in the case of copper, a given reaction is not accompanied by as great an elongation under shock as under a steady load. The tests of M. Considère on soft iron wire are quoted to show that when the ultimate elongation is the same under slow test and shock, a given elongation results in a much greater reaction in the case of shock.[1] The latter observer measured the reaction accompanying a given elongation from a falling weight by hanging the test wires to a spring.

In the second report on the influence of temperature, Le Chatelier, in addition to investigating the effect of temperature on the results of slow tests, obtained the effect of temperature on quick tests, and discusses fragility at low temperatures. From 100° to 250° C. quick tests gave a less ultimate load and a greater per cent of elongation than slow tests at the same temperature. Above 300° C. the reverse occurred. While lack of shock-resisting capacity at the lower temperatures depended on the texture of the metal, it seemed that the texture played no part in brittleness at temperatures above 60° or 80° C., at which temperature the fracture of all grades of iron and steel was fibrous when at ordinary temperatures the fracture was coarse.[2] The contraction of hard and soft steel approached equality as the temperature was raised. The temperature of greatest brittleness depended on the speed of test. That is, while in slow tests the resilience was least at 300° to 350° C., the resilience under shock was least at about 500° C.

With slow tests, low temperatures give increased elongation,[3] but shock tests show less elongation at low than at normal temperature. The experimental evidence of decreased shock resistance at low temperatures is large. Thus, Sandberg, 1867, in the case of iron rails, found a diminution of shock resistance at 12° C. to 1/3 to 1/4 part of that at 28° C., the deformation being 1/4 part of that at 28° C.

[1] Prof. J. B. Johnson, in his "Materials of Construction," has plotted these results of M. Considère in the shape of a stress-strain diagram and shown that the area of the latter for soft iron wire is about 30 per-cent greater under shock than under a steady load.

[2] This difference of fracture was also noted by Andrews on wrought-iron car axles under impact.

[3] *i. e.*, in tests of Le Chatelier, and others at the Berlin Testing Laboratory, and Cornell University.

M. Bernadou, for both soft steel and hard steel in flexure, observed a greatly decreased resilience under shock at $-60°$ compared with $+15°$ C., the decrease being less for hardened steel. These results were confirmed by Le Chatelier. At 100° C. the elongation increased. A nicked steel bar which broke without deflection at 15° C. gave a silky fracture at 100° and then only broke after pronounced bending.

Under shock, then, either a low temperature or a high temperature will develop a minimum resilience. A temperature of maximum resilience exists between these two, which is higher than the normal atmospheric temperature.

Le Chatelier remarks, it is evident that the resilience under slow tension is not a true measure of the shock-resisting capacity of materials at different temperatures; since in the case of slow tension the per-cent of elongation increases as the temperature is lowered, whereas in shock the reverse is true. At very low temperatures under shock there seems to be elongation only at the point of rupture.

Le Chatelier further notes that at ordinary temperatures, as the speed of the machine increases the ultimate load increases, but the yield points are raised more rapidly. Thus, as the speed increases the stress-strain curve becomes flatter and the elongation is confined to the weaker parts of the bar. The tendency of a bar broken quickly to form knobs is also referred to. Le Chatelier observed also the effect of low temperatures at a given test speed, in elevating the elastic limit toward the ultimate strength; and remarks that any cause, whether low temperature or quick speed or phosphorus which increases the ratio of the elastic limit to the ultimate strength will tend to produce brittleness. Tests with tempered wire showed that the resilience was much less affected by speed than in the case of annealed wire.

A series of tests in longitudinal shock, with accompanying tests in slow tension, has been made at Purdue University during the past two years on iron and steel wires from 1/8 to 1/3 inch in diameter, ranging in length from 4 to 9 feet. Results from 62 specimens have been obtained. The experiments will be continued next year on an improved machine, and with material more homogeneous than that used heretofore. The machine is of a type previously noted, the hammer being hung on the specimen and impact taking place at the upper head. The hammer varied from 845 to 1230 pounds, the range of motion being from 1/4 to 7 feet. The specimens were ordinarily broken with one blow, so that the conditions were met of (1) a heavy hammer of low velocity; (2) large inertia of everything except the specimen; and (3) the use of a single blow. The anvil on which impact occurred at the upper head consists of two oak pieces $4 \times 4$ inches in section, bridging 20 inches clear span between up-

rights of machine, supporting a cast-iron block 14 inches by 18 inches by 6 inches thick, which in turn supported a steel block $4 \times 4$ inches in section and 14 inches long.

Some of the energy was absorbed at the anvil or bridge, but as the maximum reaction developed in the wire was 6,000 pounds and the deflection at the bridge did not exceed 1/16 inch, whereas the elongation of the specimen was usually 12 to 18 inches, the proportion of work absorbed was small. Thus, with 14 inches elongation of specimen it would be less than 1 per-cent.

A pencil attached to the hammer describes a curve on the surface of a revolving drum, whose speed is determined by the record of a tuning fork. The total elongation of the specimen is thus recorded on the drum, as well as the velocity of the descending weight before and after impact. The total work done on the specimen and at the bridge is equal to the loss of kinetic energy of the hammer plus the weight of the hammer into the elongation of the specimen, the friction on the guides, and the work done in compressing the wedges being neglected. By drawing successive tangents to the velocity-displacement curve recorded on the drum, and determining the acceleration at successive points, a load elongation diagram, or stress-strain curve is obtained.

The specimen is held by conical wedges, fitting into a proper hole in cylindrical steel bushings.

In the tests referred to, the wedges were driven tightly and no slipping of the specimen in the wedges could be detected. A summary of the observations shows that the ultimate elongation, contraction of area and resilience were not different for Norway iron and medium steel wire about 1/3 inch in diameter under slow loading and impact. A greater elongation and contraction of area occurred under shock in the case of hard steel wire, and in the case of softer wire of 1/8 inch in diameter. The effect of temperature on elongation and resilience of Norway iron was marked.

One specimen broke in two places, and in other cases more than one neck developed in the specimen. In impact on wires of smaller diameter the elongation in the different foot-lengths varied apparently without any regularity, while in the case of slow-tension tests on the same material the elongation decreased regularly on each side of the fracture. In the case of thick wires the elongation was as uniformly distributed in slow as in rapid tests. Tests of Norway iron at low temperature developed knobs in the specimen, the elongation being confined to the length between knobs. These knobs were not noticeable at 210° F. The erratic behavior of some specimens indicated clearly that the material was not homogeneous. Detailed results will be published when the investigation is sufficiently advanced.

Tension tests under impact have been carried out by Prof. Martens, but have proved so far of little promise. Tension tests were made on round bars 0.8 inch in diameter, of soft steel and bronzes. The deformation became less as the energy of the blow became greater. In general, the appearance of the surface of rupture was found alike in all respects under impact and slow stress. By rupture with several blows, the elongation was frequently greater than under slow tension.

### *Compression Tests.*

The investigation of impact tests of metal in compression has been extended by Professor Martens and he has proposed specifications for their conduct. The form of test piece suggested is a cylinder of a diameter equal to the length, or a cube of equal volume. Rupture or a shortening of 0.8 is to be produced at a single blow, after a series of trials. Within the limits of size of hammer and height of fall used in the ordinary machines, the influence of speed of delivery of a given amount of energy does not seem important. After the blow, the specimen is drawn out by an attached cord to prevent the second blow, due to the recoil of the hammer. To insure uniform conditions of friction between the specimen and the hammer and anvil, it is recommended that these surfaces shall be treated with graphite. Greater deformation results from lubricated surfaces. The phenomena of rupture were found to be essentially the same in impact as in slow testing. It was noted that for a given specimen and hammer, a single heavy blow of a given energy will produce a greater deformation than a number of light blows of the same total energy.

A very precise measurement of the reaction and accompanying deformation under impact in compression was made by Lieut. Dunn. The deformation of the copper test piece was indicated by the rotation of a small mirror, and the consequent travel of a beam of light along the surface of a rapidly rotating cylinder covered with a photographic film. From this velocity-displacement curve, the load-elongation curve was obtained which showed somewhat higher reactions for a given deformation than in the case of a load gradually applied.

### *Flexure Tests.*

The tests of W. Bent Russell on cast iron confirm former conclusions with regard to proportionality of resilience to volume. His results on ductile metals are affected by the notching (to 1/4 depth) of the test bars. This, of course, had the effect of confining the deformation largely to the notch. No satisfactory comparisons can be made between shock tests on such bars, and slow tests on unnotched bars of the same depth.

Thos. Andrews' test on axles bear out other observations as to the appearance of the fracture ; *i. e.*, wrought iron axles having a crystalline fracture at — 18° F. showed a fibrous fracture at 300° F. The axles were subjected to flexure in opposite directions under the impact of a hammer. The number of flexions for rupture was a minimum at 570° F. Even a change of temperature from 32° F. to 212° F. diminished the number of flexions from 17 to 10. Other tests by Andrews at 0° and 100° F. showed that the total number of blows to fracture was increased, on the average, from 23.8 at 0° F. to 37.1 at 100° F. In this case the 4 1/2 inch axles were subjected to the impact of a hammer of 2240 pounds falling 30 inches on a span of 3 1/2 feet. The temperature was restored, and the axle turned over after each blow. The average deflection per blow was the same at either temperature.

Professor Merriman found that the impact of a wooden ball on roofing slate furnished a good comparative measure of quality.

M. Hallopean showed that the loss of ductility in punching iron and steel plates, and the benefits of subsequent annealing, are best revealed by impact tests.

Prof. Tetmajer's tests in bending or solid and built beams of mild steel and wrought iron showed the great superiority of the former metal under shock.

Professor Talbot subjected wooden and steel beams to impact action and verified the theoretical formulas for deflection.

### *Conclusions.*

From the foregoing it appears that in general the elongation at rupture produced by a number of blows is larger than that in the case of a slow tension test, but that the elongation at rupture under a single blow is at times the same or less than in slow tension and at other times much greater. The reason for these variations are not yet determined. The variations are doubtless affected by the size of the specimens as well as the character of the material. The amount of the variation seems to be quite different in specimens of the same shape and apparently of the same quality. More extended investigations are needed before definite conclusions can be drawn. However, it is not to be expected that impact tests should give as uniform results as loads gradually applied.

The decreased resilience of material under impact at low temperature, is fairly well determined. An increased reaction under shock for a given deformation is to be expected and is confirmed by experiment. On account of the more general sharing of the whole bar in the elongation, and, at times the formation of more than one neck the elongation should be greater in

impact, although this tendency in certain cases may be counteracted by the influences which bring about the observed knobby condition of the bar after rupture. It should be remembered that the total resilience is a function of the maximum elongation; namely, that just before breaking, and that the elongation after breaking is not always a true measure of this maximum elongation. At any rate the fact is well known that certain materials, as for instance, pitch or sealing wax, which exhibit a fair degree of strength and ductility under loading gradually applied can not endure even very slight deformation from shock without rupture. This is true, also, although the contrast is less marked, of rails high in phosphorus.

The opinion is widespread in practice that many defects of mechanical treatment can only be brought to light under the action of impact.

It is generally assumed that the ability of a metal to resist shock without rupture is expressed by the elongation at breaking combined with the ultimate stress, the elongation being the more important factor. However, in the case of material for armor plate, it is well known that a hard face is necessary to withstand the projectile. Here the valuable property of the material is that which enables it to quickly transfer the blow throughout a large body of metal. And this ability of metal to absorb shock by its prompt transmission throughout the mass must be kept in mind, as well as the shock resistance due to ductility.

In this connection it may be again remarked that a test involving rupture under a number of blows is not comparable to a test using one blow of the same total energy. Each successive blow must first overcome the elastic recovery from the preceding blow before it can increase the permanent deformation. Again, in compression, the effect of the first blow, or first few blows, is also to harden the metal. This hardening may result in a decreased resistance to the second blow. In some cases there may be a beneficial effect from a number of small blows.

## American Commercial Tests.

### *Axle Tests.*

The practice in this country is quite uniform. The usual conditions are: Weight of hammer, 1640 pounds; anvil, 17,500 pounds on 12 springs; supports curved to 5-inch radius; span, 3 feet. The foundation is usually natural ground. The Pennsylvania Railroad specifications are generally followed quite closely. Steel axles 4 3/4 inches in diameter at center must not rupture under 5 blows from a height of 34 feet, and the deflection from the first blow must not exceed 8 inches. The axle is turned over after the first and third blows. Some specifications require the

axle to be turned over after each blow. Height of fall varies with diameter of axle.

*Car-Wheel Tests.*

The wheel is usually held on three supports, not more than 5 inches wide, resting on a rubble foundation 2 feet deep. The common specifications for 33-inch wheels are: Weight of hammer, 140 pounds; weight of anvil, 1700 pounds; ten blows to be delivered from a height of 12 feet, on center without rupture. The number of blows is varied with the size and weight of the wheel.

*Rail Tests.*

The usual conditions for rail tests are as follows: Span, 3 feet; length of specimen, 4 feet; about one piece in 100 tons tested; weight of hammer, 2000 pounds; weight of anvil (Carnegie), 5920 pounds; base-plate, 4250 pounds.

The Northern Pacific Railroad specifications require a rail butt from each conversion to be placed either head or base upwards on solid steel or iron supports, the distance apart of which is 3 feet for sections up to and including 70 pounds, and 4 feet for all heavier ones. The hammer weighs 2000 pounds and falls freely from a height of 16 feet for 70-pound, and 20 feet for all heavier rails. The rail must not break under one blow.

*Cast-Iron Tests.*

The Baltimore and Ohio Railroad specifications for locomotive castings require drop test specimens, one inch square and 13 inches long, to be tested in the rough, resting on firm supports 12 inches apart. Specimens must stand 5 blows of a ten-pound weight, striking midway between the supports, the first blow being from 15 inches for castings, requiring special strength, and from 12 inches for ordinary locomotive castings. The height of fall is increased one inch for each blow succeeding the first.

At the Pencoyd Iron Works impact tests are occasionally made on cast-iron specimens, which are 1 inch square and 14 inches long. A guided hammer, whose weight is 100 pounds, strikes the specimen midway between the supports, which are 12 inches apart. Beginning with a drop of 3/4 inch and increasing this 1/16 inch each succeeding blow, the test is continued to rupture. The resistance to impact appears to be extremely variable, fracture occurring at an average drop of 1 3/4 inches, with a range of from 1 to 2 3/8 inches. In the standard transverse test a similar specimen, similarly supported, must sustain a pressure of 2400 pounds, and deflect 15/100 inch before fracture. The material has an average tensile strength of 16,000 pounds.

At the works of the Bethlehem Iron Company impact tests are used, but not for the purpose of satisfying specifications. The specimens used are 1/2", 3/4" and 7/8" square, 5, 6 and 8 inches long. Specimens are cut from forgings, and also rolled to size. The hammer weighs 40 pounds and the anvil one ton.

### *Car-Coupler Tests.*

The drop test for couplers, adopted by the Master Car Builders' Association, requires the use of a machine with spring foundation. The foundation of the proposed machine is of brick, 8 feet by 8 feet at top, 12 feet by 12 feet at bottom, and 8 feet deep. On this foundation is a cut stone cap 6 feet by 6 feet by 18 inches. Bolted through to the foundation and resting on this cap is a 5-foot by 5-foot by 4-inch cast-steel foundation plate. A 1/8-inch layer of sheet lead is interposed between this stone cap and the cast-steel plate.

Twelve springs of specified quality and size are interposed between the foundation plate and the anvil, which is a cast-steel block in a cast-iron anvil, the mass weighing 24,000 pounds and of dimensions: 5 feet by 5 feet by 27 inches. The cast-steel hammer weighs 1640 pounds.

Blows are struck on the knuckle and on the guard arm while the coupler is wedged in upright position with shank resting on the anvil. The specifications give the number of blows to break the knuckle, or cause cracks of definite size, or distort the shank, or to close the knuckle a specified amount.

Provision is made in the machine for what is called the jerk test. For this purpose two cast-steel pedestals, on opposite side of the machine, anchored to the anvil, carry yoke forgings. Between these yoke forgings and the pedestals, springs are interposed. A coupler is hung to each pedestal by the yoke forging, and an "equalizer bar" connects the two couplers, resting on the closed knuckles. The hammer strikes this equalizer bar. The specifications state the number of blows to break the knuckles, or to cause cracks, or to open the knuckle.

A pulling test for complete couplers, and a separate fall test on the knuckle, when the latter is laid horizontally on the anvil, accompany the tests mentioned.

In general, shock tests are not made at a temperature below 32° F. It is to be observed, also, that the axle test, as conducted, does not simulate the conditions of service.

## German Commercial Tests.

Late German practice in testing manufactured forms for railroad work has been analyzed by Martens. The following is a brief synopsis:

*Rails.*

Supported length, 1 metre; length of specimen, 1.3 m., without fish-plate holes. The deflection is measured at the upper surface with reference to a length equal to the span. In late practice cushion blocks are not prescribed. The energy of the blow is specified at 1500, 1000 or 750 kg. m. for rail weights of over 23.8, 20 to 23.8, and 16 to 20 kg. per running metre, respectively.

The extension or compression on the surface of the rail is measured by means of a scale marked on the rail before testing.

Martens recommends a study of the scale forms which appear on the surface of test pieces. These are closely allied to structure and chemical composition. The forms are alike for impact and slow tests.

*Axles.*

Length of support, 1.5 m.; energy of blow, 3000 kg. m.; test piece not turned over. For locomotive axles, energy of blow, 5600 kg. m. (7 m. × 800 kg.). Tender axles, 4200 kg. m. (7 m. × 600 kg.). The deflection is measured at the upper surfaces as in rail tests.

*Tires.*

Tested in upright position with blow of 3000 kg. m. Diminution of inner vertical and increase of inner horizontal diameter measured after each blow. Blows continued until a specified deflection of inside diameter is reached. Thermal conditions to be noted. Tension tests to accompany impact tests on pieces least bent by blow.

In the *Vorschriften für Lieferungen von Eisen und Stahl, aufgestellt vom Verein Deutscher Eisenhüttenleute, 1893*, drop tests are specified for rails, tires, and axles.

*For Rails.*—Drop tests for rails are to be made upon a legally gaged drop-testing machine. Supports to be one meter apart. One blow, the energy of which shall not be less than:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| For rails of | 130 | mm. height, and | over | 30 | kg. wt. per m. | 3000 | kg. m. |
| " " " | 120 | " " | " " | $27\frac{1}{2}$ | " " " " | 2000 | " " |
| " " " | 110 | " " | " " | 23 | " " " " | 1500 | " " |
| " " " | 100 | " " | " " | 20 | " " " " | 1200 | " " |

to be applied and the test continued with blows of 1200 kg. m. until rails of 130 mm. height have deflected 110 mm. For rails of a height other than 130 mm. the deflection shall be measured proportional to such heights of rails. The test is to be discontinued if the test piece deflects sideways before the minimum deflection of 110 mm. is obtained.

*For Tires.*—Drop tests on tires to be made on a legally gaged drop-testing machine. Blows, equal to 3000 kg. m. to be continued until the tire has deflected 12 per-cent of its inside diameter. The material is not to show any cracks before this per-cent of deflection is reached.

*For Axles.*—Drop tests on axles are to be made on a legally gaged drop-testing machine. Supports to be 1.5 m. apart. Blows of 3000 kg. m. to be delivered until axles of 130 mm. diameter show a deflection of 200 mm. measured between punch marks, originally 1.5 m. apart. On axles of diameters, other than 130 mm. diameter, the minimum deflection shall be measured proportional to the diameter.

The committee sent out circulars, of a form shown in the Appendix, to prominent railways and manufacturing plants, to leading technical schools, and to engineers likely to be interested in impact tests. On the whole, the returns evinced a not very lively interest in the matter of impact tests, but unexpected uniformity of practice. Commercial tests were found to be practically limited to rails, axles, couplers, and car wheels.

Respectfully submitted,

W. KENDRICK HATT.
EDGAR MARBURG.

## APPENDIX.

The subjoined list of questions was sent out to:

29 Railroad Officials,
15 Manufacturing Plants,
15 Technical Schools,
10 Engineers,
3 Others. Total 72.

1. Company represented....................................
2. Kind of impact test (tension, compression, flexure)........
3. Piece tested (as for instance, test-bar, axle, rail, etc.)......
4. Size of piece........................................
5. How selected........................................
6. How treated or prepared for tests........................
7. Disposition of supports..................................
8. Disposition of piece on supports.........................
9. Temperature at which tests are made....................
10. Foundation ........................................
11. Soil ................................................
12. Weight and size of hammer.............................
13. Weight and size of anvil................................
14. Guides ..............................................
15. Height of fall........................................
16. Specifications to which material must conform............
17. Opinion as to the value and application of impact tests......
18. Persons of whom inquiries might be made ................

Replies were received from:

12 Railroad Officials,
9 Manufacturing Plants,
6 Technical Schools,
6 Engineers,
2 Others. Total 35.

Of these a total of 18 yielded information:

6 Railroad Officials,
5 Manufacturing Plants,
4 Technical Schools,
3 Engineers.

Some of the opinions expressed in reply follow:

From Paul Kreuzpointner, Pennsylvania Railroad:

"As to my personal non-authoritative opinion on the value of impact tests, I hold that whatever structural material is subjected to shocks and tremors, should be subjected to some kind of impact test, that is dynamic test. By this I mean the application of a blow, or blows, sudden enough to prevent the particles of the metal from preparing, or adjusting themselves, partly, or wholly, to receive or cushion the force of impact. The answer to the question why this should be so, we find in the structure of iron and steel. For the same reasons I consider the static force of a slow pull, as exerted in the testing machine for tensile test, as inadequate and useless as a means of determining the shock-resisting capacities of iron and steel. This conviction has been forced upon me not by a few isolated experiments, but by the every-day experience of testing hundreds of thousands of tons of iron and steel of different grades and makes for now over seventeen years in the test room of the Pennsylvania Railroad. Almost every-day I make some nicking, or nick-bending or bending tests of materials, old or new, but mostly new, which had been tensile tested and about whose other qualities and structure I wanted to know something. A metal which adjusts itself under the slow pull of a tensile test and meets specifications for strength and elongation nicely is by no means always able to transmit and distribute through the mass of the metal, from particle to particle, the violent vibrations and tremors caused and set in motion on the circumference of the metal, with sufficient rapidity so as to prevent overstrain, or rupture, of portions of the metal, before the other portions have had time to take part in the work of resisting the extraneous forces tending to destroy the metal. This experience does not only refer to steels of the axle grade, but also to that of boiler grade and wrought iron. There are some things about iron and steel, particularly the latter, which are matters of course to the very few experts who have the opportunity to constantly handle large masses of metals and to study their inner consciousness, as it were, but which are looked upon as mysteries by the average engineer, or are brushed haughtily aside as nonessentials, or because they cannot be squeezed into the straightjacket of mathematical rules and formulas."

From A. N. Talbot, Professor of Municipal and Sanitary Engineering, University of Illinois:

"Of great value for pieces subject to impact, and for brittle and uneven material. In these and in other cases, there is urgent need of thorough investigation of the phenomena."

From J. E. Greiner, Engineer of Bridges and Buildings, B. & O. R. R.:

"Rail impact tests are valuable only for purposes of comparison of different rollings."

From F. A. Delano, Superintendent of Motive Power, C. B. & Q. R. R.:

"My opinion of impact tests is that they are excellent for any material which in use is subjected to impact, and I think that all tests should be made to conform as closely as possible to service conditions."

From N. Y. C. & H. R. R.:

"Valuable to a limited extent in determining comparative quality and workmanship in axles."

From the Engineer of Tests, Bethlehem Iron Company:

"Will no doubt be of considerable value when thoroughly understood and will admit of more or less application."

From J. R. Onderdock, Engineer of Tests, B. & O. R. R.:

"Impact tests good for pieces subject to shock and sudden strains, but when made on steel should be accompanied with chemical tests."

From Report of the American Foundrymen's Committee on Standardizing the Testing of Cast Iron:

"It is regretted that no machinery is available for reliable impact tests, our committee deeming this method of testing a most important one, the only one in fact giving a true insight into the resistance of cast iron to shock. The future will doubtless bring this test forward more prominently, but whether in time for our work or not can not yet be said."

From Dr. R. Moldenke, Superintendent Pennsylvania Malleable Company:

"I consider the impact test as a most important one, for a great majority of finished materials in service fail through vibration or shock. Special study should, however, be directed to carrying out impact tests in better conformity with the teachings of actual service failures. Thus, in the tests made upon couplers, both pulling and drop, the failures observed are not comparable

with actual breakages, as seen on the scrap pile. Perhaps a closer study will account for some of this. The heaviest breakages in couplers, guard arms excepted, is in the lugs. An inspection of tens of thousands of these breakages would give an impression that they were all pulled off, and yet close investigation reveals the fact that 80 per-cent were first battered up, by impact, and then pulled through the cracks. Here is explained the tendency to call for high tensile strength, when really what is wanted is high resistance to impact. I should be glad to see impact tests developed on two lines. First, on test specimens, and second, on finished work. On the tests specimen I would prefer the blow delivered at the free end of a tightly fixed bar as more nearly the situation in actual service."

From A. S. Vogt, Mechanical Engineer, Pennsylvania Railroad:

"We can only add that we believe for certain classes of material the impact test is the only one that gives results of value. For the axle test, as conducted for many years, we concluded that much was to be desired, owing to the uncertain quantity of the resistance offered by the anvil and foundation, our attention having been called to various cases where the results of drop tests of axles of the same height were so divergent that they could only be ascribed to the difference in resistance. It was evident that this resistance would also vary on the same drop-test machine, owing to the resistance being very much greater on the ground when the anvil was frozen. It was also evident that due to variations in the different soils where axle drop-test machines might be placed, the results could not be compared one with the other, and, therefore, it was decided that for the sake of unformity the resistance due to the nature of the soil should as far as possible be eliminated, and it was determined that the resistance to impact would be the mass of the weight of the anvil itself, and that this anvil should be supported on springs, so as to be as nearly as possible independent of the variations in the soil, and this is the principle embodied in our present axle testing machine. Machines embodying this principle are now to be found at Altoona, Pa., in the works of this Company; Midvale Steel Works, Philadelphia, Pa.; Pencoyd Iron Works, Philadelphia, Pa.; Otis Steel Co., Cleveland, Ohio; Pittsburg Forge and Iron Company, Pittsburg, Pa.; Carnegie Steel Company, Pittsburg, Pa.; Keystone Axle Company, Beaver Falls, Pa.; and probably also the Block–Pollak Iron Company, at Cincinnati, O. We believe from the results obtained that the shock test reveals the defects in the heat treatment, which defects can not be shown in any way by tensile tests."

From Dr. Charles B. Dudley, Chemist, Pennsylvania Railroad:

"Our judgment in this matter is this: As we are getting more and more experience all the time, we are constantly trying to test the material just as we put it in service, rather than a piece of it, that is to say, we test a whole axle, rather than a piece cut out of it, we test a whole car wheel, rather than a fragment of it, and so on. Obviously for this purpose either very large testing machines are required, or else we must use the impact test. We have accordingly expanded quite a little in recent years, in impact testing, and with the construction of machines which the Pennsylvania Railroad requires, we are inclined to think that the impact test is a genuine, scientific test, provided, of course, deflection is taken as one of the elements. In our judgment impact testing will continue to increase."

From Max H. Wickhorst, Engineer of Tests, C. B. & Q. R. R.

"Impact tests are used by railroads in buying wheels, axles, and automatic car couplers and they have decided value for the purpose of keeping material up to a predetermined standard. For instance, our company some time ago placed an order with a firm for some steel M. C. B. car couplers, which had not before supplied us with any couplers; although they were very confident that they could furnish material to stand our tests; still, when I came to make actual tests with the drop machine, the material failed requirements and I rejected the lot. This resulted in a change in their foundry organization and method of keeping records, and when afterwards, couplers were presented for inspection, the required samples stood the drop test satisfactorily. This is a case where the impact test was used to elevate the standard of quality of an important commercial article turned out by this firm."

From Thos. D. West, Foundry Expert, Sharpsville, Pa.:

"In replying to the request for views and experiences on impact tests, the writer would give it as his opinion that when it is practicable to apply such tests to castings, after the methods used in testing car-wheels, he considers that they will indicate fairly what may be expected of such castings when subjected to shocks or slight changes of temperature.

"Impact tests on the side of test-bars, the writer considers of no value in denoting what may be expected of castings, unless experience with castings made from the same mixture has shown what may be expected of them, and a record is kept of the contraction and analyses of mixtures. This necessity of first knowing what a special form of casting will stand in actual service, before an impact test-bar record can be of any value as a compara-

tive measure, causes impact tests on test-bars to be a very roundabout way of obtaining knowledge.

"It is sometimes thought that if test-bars prove strong under impact tests, castings made from the same iron will resist shocks or jars to an equal degree. But the property of castings to resist shock is, as a rule, as much dependent upon their form and proportions as upon the grade of the metal. In fact, castings may be constructed from iron showing the weaker result in test-bars, which will prove stronger under impact tests or usage. This is due, first, to the fact that strong or hard iron possesses a greater contraction than weak or soft iron, and, second, that light bodies will contract more than heavy ones, made from the same iron. In illustration, the writer would call attention to experiments which he conducted to find the difference in the contraction of two castings, each 14 feet long, one being $1/2 \times 2$ inches, and the other $4 \times 9$ inches in cross section. Both pieces were poured of the same iron and at the same time. This experiment gave a contraction of 1 3/4 inches for the light and 7/8 inch for the heavy body; *i. e.*, the light body contracted as much again as the heavy one.

"Considering that the lighter parts of castings possess a greater contraction than the heavier parts, if left free to act, as proven by the tests just cited, it will be seen that an internal strain must exist in all such castings. Again, when we consider that strong or hard iron possesses a greater contraction than soft or weak iron, we are forcibly brought to discern why iron that shows exceptionally strong results in a test-bar may cause a casting to crack from the least jar or change of temperature. On the other hand, as soft or weak iron possesses a lower contraction, thus causing lower internal strains in castings, it will often stand much rougher usage than the test-bars would indicate."

# ANNOUNCEMENT

OF THE

# PUBLICATION COMMITTEE.

At the second Annual Meeting of the American Section, held on August 15 and 16, 1899, contributions amounting to $200 were made as the nucleus of a Fund for Publication and Research. Additional gifts have since been received, which have increased the Fund to $345. All persons desiring to contribute to this Fund are invited to address the Treasurer of the American Section, Paul Kreutzpointner, Altoona, Pa., and information regarding the work of the Association may also be obtained from the undersigned. A list of contributors to the Fund will be published in Bulletin No. 6.

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